EEC4122: Satellite Communication Systems

Radio Wave Propagation

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Introduction

- A signal traveling between an earth station and a satellite must pass through **the earth's atmosphere**, including the **ionosphere**
- this can introduce certain impairments

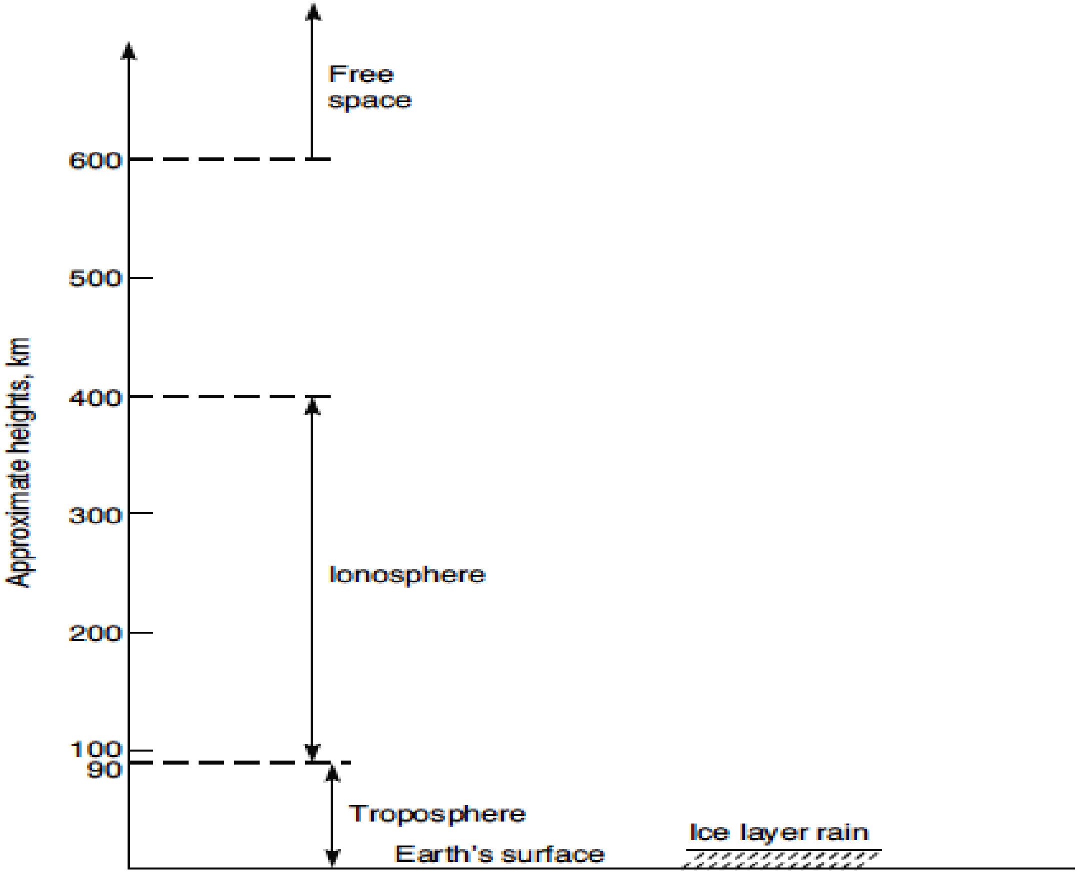


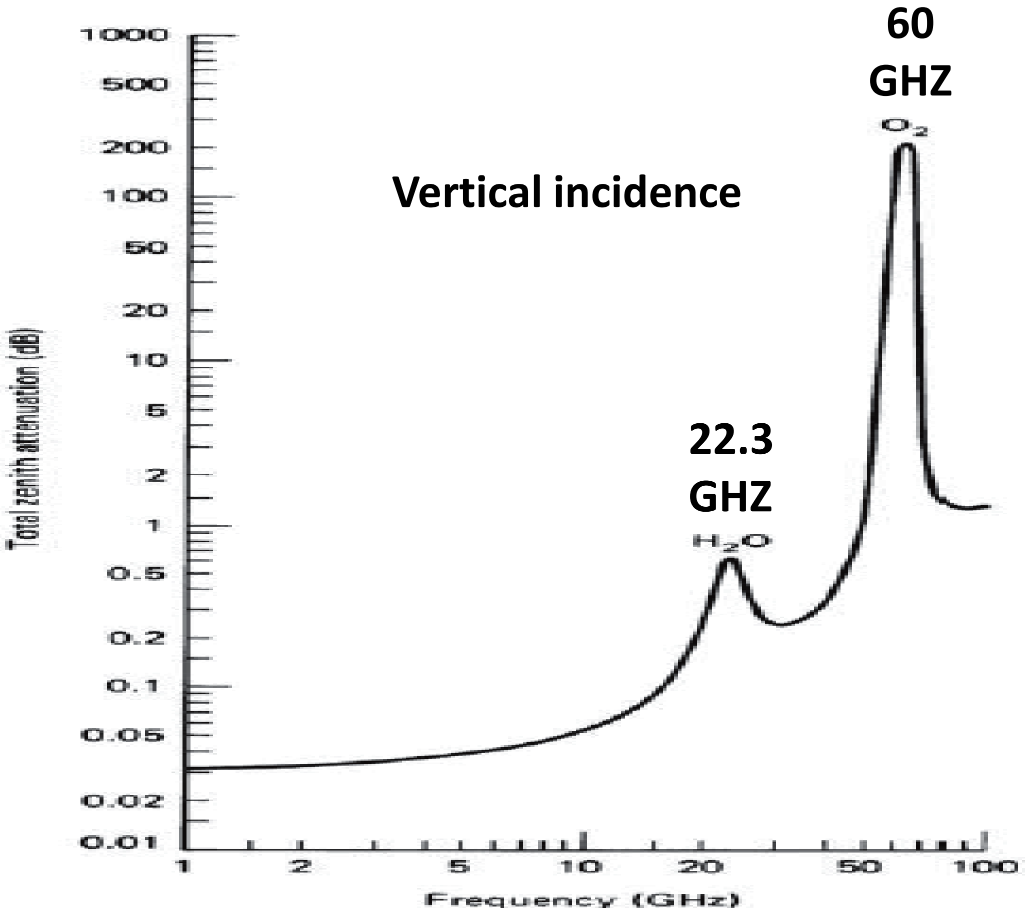
Figure 4.1 Layers in the earth's atmosphere.

Atmospheric Losses

- as a result of energy absorption by the atmospheric gases (**atmospheric absorption**)
- Different from (**atmospheric attenuation**) due to weather conditions
- Atmospheric absorption loss varies with frequency (caused by resonance)
- Absorption loss:

$$[AA] = [AA]_{90} cosecEl$$

- An effect known as **atmospheric scintillation** *(fading)* can also occur due to differences in the atmospheric refractive index (considered by a fade margin)



Ionospheric Effects

- Ionosphere is the upper region of the earth's atmosphere which has been ionized by solar radiation
- Free electrons (non-uniform) in Ionosphere travel through the ionosphere and give rise to fluctuations in the signal and result in:
  - ***scintillation***, *absorption, variation in the direction of arrival, propagation delay, dispersion, frequency change,* and ***polarization rotation***
- Inversely proportional to frequency squared
- Ionospheric scintillations (fading) are variations in the amplitude, phase, polarization, or angle of arrival of radio waves due to irregularities in Ionospheric region that change with time
- Need to include a fade margin to allow for ionospheric scintillation

Rain Attenuation

- Rain rate: the rate at which rainwater would accumulate in a rain gauge situated at the ground (earth station)(millimeter/hr)
- Time percentage: the percentage of time, of a year, the specified rain rate would be exceeded
- Rain rate is denoted by: R_p and p is time percentage (ex: $R_{0.001}$)
- Specific attenuation is: $\alpha = aR_p^b \; dB/Km$
  - a, b→ depend on frequency and polarization (Given in tables w.r.t frequency)
  - For circular polarization: $a_c = \frac{a_h + a_v}{2}$ and $b_c = \frac{a_h b_h + a_v b_v}{2a_c}$
- Total attenuation is given by $A = \alpha L$
  - L → **effective path length** in rain

Rain Attenuation

TABLE 4.2 Specific Attenuation Coefficients

Frequency, GHz	a_h	a_v	b_h	b_v
1	0.0000387	0.0000352	0.912	0.88
2	0.000154	0.000138	0.963	0.923
4	0.00065	0.000591	1.121	1.075
6	0.00175	0.00155	1.308	1.265
7	0.00301	0.00265	1.332	1.312
8	0.00454	0.00395	1.327	1.31
10	0.0101	0.00887	1.276	1.264
12	0.0188	0.0168	1.217	1.2
15	0.0367	0.0335	1.154	1.128
20	0.0751	0.0691	1.099	1.065
25	0.124	0.113	1.061	1.03
30	0.187	0.167	1.021	1

Rain Attenuation

TABLE 4.3 Reduction Factors

For $p = 0.001\%$	$r_{0.001} = \frac{10}{10 + L_G}$
For $p = 0.01\%$	$r_{0.01} = \frac{90}{90 + 4L_G}$
For $p = 0.1\%$	$r_{0.1} = \frac{180}{180 + L_G}$
For $p = 1\%$	$r_1 = 1$

SOURCE: Ippolito, 1986.

- Rain is not uniform in the path
- How to calculate effective path length in rain:
- For $El < 10^\circ$ → earth curvature
- For $El >= 10^\circ$ → earth flat

$$L_S = \frac{h_R - h_0}{sinEl}$$

- Effective length: $L = L_S r_p$
  - r_p → reduction factor and $f(p, L_G)$
- Rain attenuation is finally given by: $A_p = aR_p^b L_S r_p \ dB$

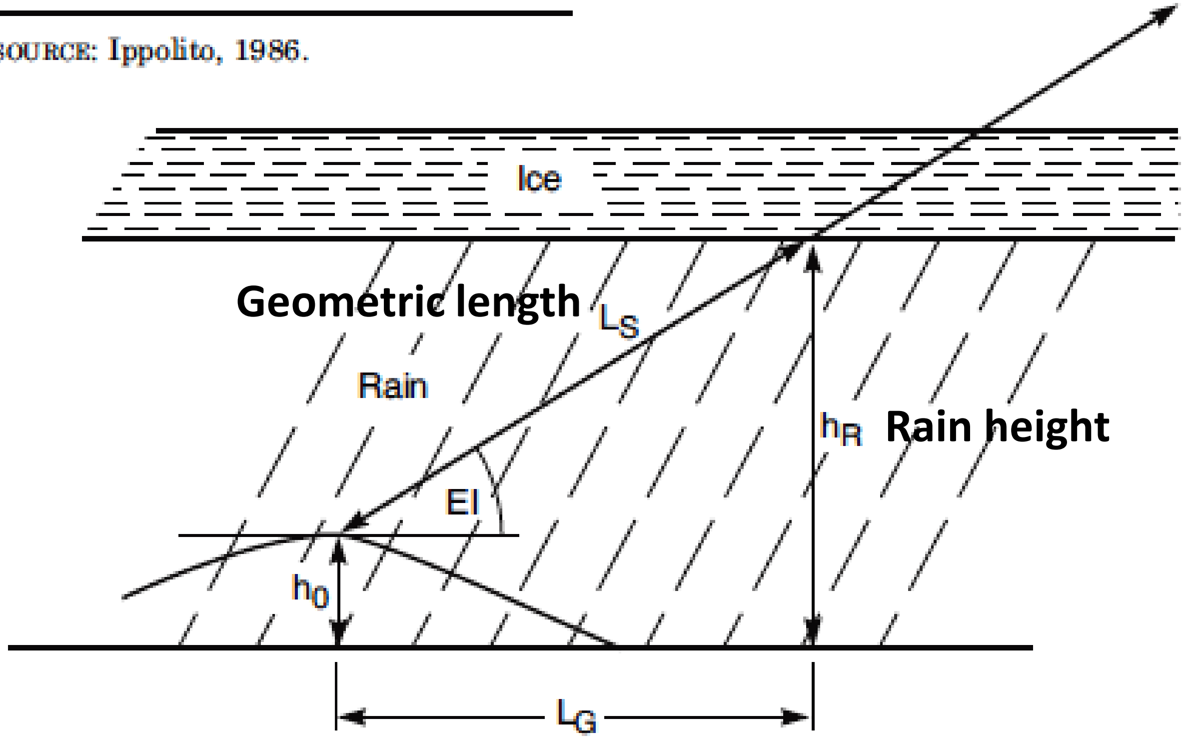


Figure 4.3 Path length through rain.

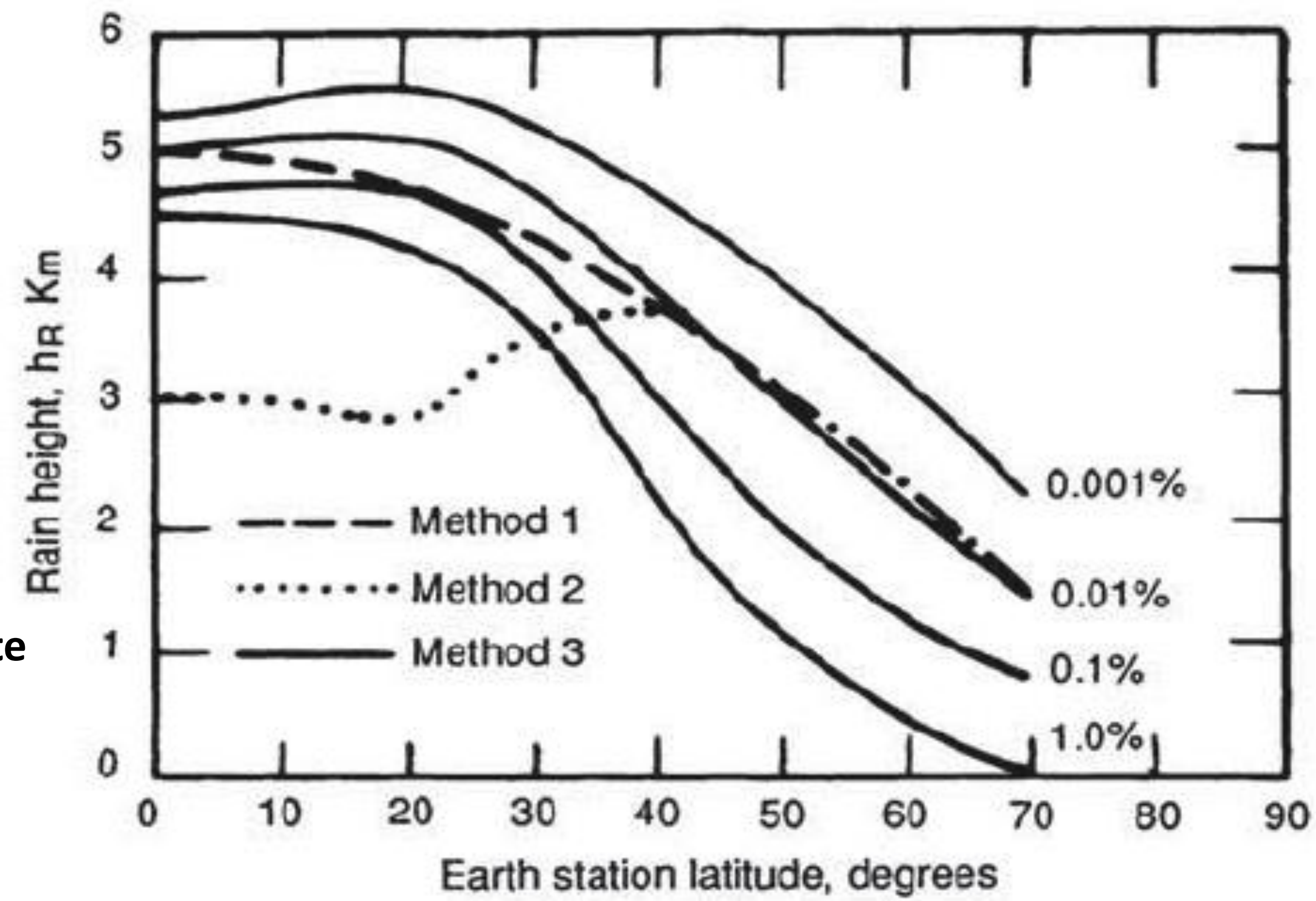
$$\boxed{L_G = L_S cosEl}$$

Rain Attenuation

Maritime climate

Tropical climate

Continental climate



Rain Attenuation

- **Example:** Calculate, for a frequency of 12 GHz and for horizontal and vertical polarizations, the rain attenuation which is exceeded for 0.01 percent of the time in any year, for a point rain rate of 10 mm/h. The earth station altitude is 600 m, and the antenna elevation angle is 50°. The rain height is 3 km.

Rain Attenuation

$$El = 50°;\ h_0 = 0.6;\ h_r = 3;\ R_{01} = 10$$

From Eq. (4.4):

$$L_S = \frac{h_R - h_0}{\sin El}$$

$$= \frac{3 - 0.6}{\sin 50°}$$

$$= 3.133 \text{ km}$$

From Eq. (4.6):

$$L_G = L_S \cos El$$

$$= 3.133 \cos 50°$$

$$= 2.014 \text{ km}$$

From Table 4.3, the reduction factor is

$$r_{01} = \frac{90}{90 + 4L_G}$$

$$= 0.9178$$

For horizontal polarization, from Table 3.2 at $f = 12$ GHz; $a_h = 0.0188$; $b_h = 1.217$
From Eq. (4.7):

$$A_p = a_h R_{01}^{b_h} L_S r_{01}$$

$$= 0.0188 \times 10^{1.217} \times 3.133 \times 0.9178$$

$$= \underline{\underline{0.891 \text{ dB}}}$$

For vertical polarization, from Table 3.2 at $f = 12$ GHz; $a_v = 0.0168$; $b_v = 1.2$

$$A_p = a_v R_{01}^{b_h} L_S r_{01}$$

$$= 0.0168 \times 10^{1.2} \times 3.133 \times 0.9178$$

$$= \underline{\underline{0.766 \text{ dB}}}$$

Rain Attenuation

- **<u>Example:</u>** Repeat the example for circular polarization.

Rain Attenuation

Solution From Eq. (4.8a):

$$a_c = \frac{a_h + a_v}{2} = \frac{0.0188 + 0.0168}{2} = 0.0178$$

From Eq. (4.8b):

$$b_c = \frac{a_h b_h + a_v b_v}{2a_c} = \frac{0.0188 \times 1.217 + 0.0168 \times 1.2}{2 \times 0.0178} = 1.209$$

From Eq. (4.7):

$$A_p = a_c R_{01}^{b_c} L_S r_{01} = 0.0178 \times 10^{1.209} \times 3.133 \times 0.9178 = \underline{\underline{0.828\ \text{dB}}}$$

Other Propagation Impairments

- Hail, ice, and snow have little effect on attenuation because of the low water content
- Ice can cause depolarization
- The attenuation resulting from clouds is generally much less due to low water content

Summary

TABLE 4.1 Propagation Concerns for Satellite Communications Systems

Propagation impairment	Physical cause	Prime importance
Attenuation and sky noise increases	Atmospheric gases, cloud, rain	Frequencies above about 10 GHz
Signal depolarization	Rain, ice crystals	Dual-polarization systems at C and Ku bands (depends on system configuration)
Refraction, atmospheric multipath	Atmospheric gases	Communication and tracking at low elevation angles
Signal scintillations	Tropospheric and ionospheric refractivity fluctuations	Tropospheric at frequencies above 10 GHz and low-elevation angles; ionospheric at frequencies below 10 GHz
Reflection multipath, blockage	Earth's surface, objects on surface	Mobile satellite services
Propagation delays, variations	Troposphere, ionosphere	Precise timing and location systems; *time division multiple access* (TDMA) systems
Intersystem interference	Ducting, scatter, diffraction	Mainly C band at present; rain scatter may be significant at higher frequencies

SOURCE: Brussard and Rogers, 1990.